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Part B

BASEBAND SPECIFICATION

This document describes the specifications of the Bluetooth link controller which carries out the baseband protocols and other low-level link routines.

CONTENTS

1 GENERAL DESCRIPTION

Bluetooth is a short-range radio link intended to replace the cable(s) connecting portable and/or fixed electronic devices. Key features are robustness, low complexity, low power, and low cost.

Bluetooth operates in the unlicensed ISM band at 2.4 GHz. A frequency hop transceiver is applied to combat interference and fading. A shaped, binary FM modulation is applied to minimize transceiver complexity. The symbol rate is 1 Ms/s. A slotted channel is applied with a nominal slot length of 625 µs. For full duplex transmission, a Time-Division Duplex (TDD) scheme is used. On the channel, information is exchanged through packets. Each packet is transmitted on a different hop frequency. A packet nominally covers a single slot, but can be extended to cover up to five slots.

The Bluetooth protocol uses a combination of circuit and packet switching. Slots can be reserved for synchronous packets. Bluetooth can support an asynchronous data channel, up to three simultaneous synchronous voice channels, or a channel which simultaneously supports asynchronous data and synchronous voice. Each voice channel supports a 64 kb/s synchronous (voice) channel in each direction. The asynchronous channel can support maximal 723.2 kb/s asymmetric (and still up to 57.6 kb/s in the return direction), or 433.9 kb/s symmetric.

The Bluetooth system consists of a radio unit (see Radio Specification), a link control unit, and a support unit for link management and host terminal interface functions, see Figure 1.1 on page 41. The current document describes the specifications of the Bluetooth link controller, which carries out the baseband protocols and other low-level link routines. Link layer messages for link set-up and control are defined in the Link Manager Protocol on page 185.

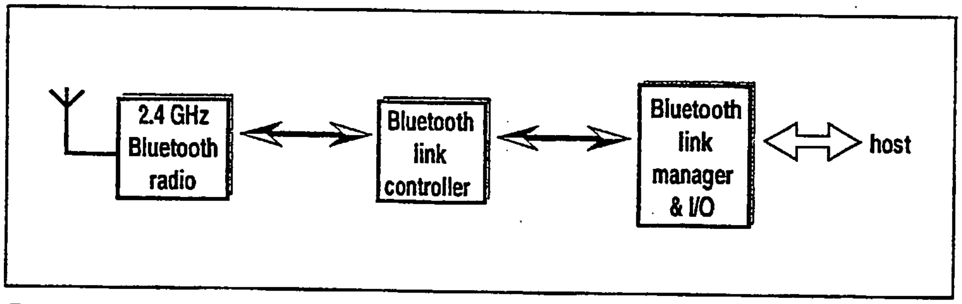

Figure 1.1: Different functional blocks in the Bluetooth system

The Bluetooth system provides a point-to-point connection (only two Bluetooth units involved), or a point-to-multipoint connection, see Figure 1.2 on page 42. In the point-to-multipoint connection, the channel is shared among several Bluetooth units. Two or more units sharing the same channel form a ***piconet***. One Bluetooth unit acts as the master of the piconet, whereas the other unit(s)

acts as slave(s). Up to seven slaves can be active in the piconet. In addition, many more slaves can remain locked to the master in a so-called parked state. These parked slaves cannot be active on the channel, but remain synchronized to the master. Both for active and parked slaves, the channel access is controlled by the master.

Multiple piconets with overlapping coverage areas form a ***scatternet***. Each piconet can only have a single master. However, slaves can participate in different piconets on a time-division multiplex basis. In addition, a master in one piconet can be a slave in another piconet. The piconets shall not be time- or frequency-synchronized. Each piconet has its own hopping channel.

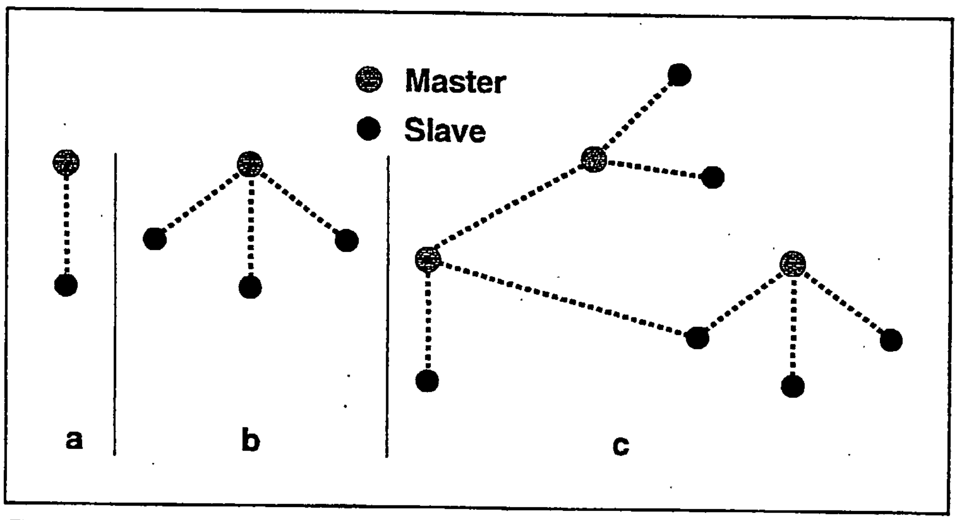

Figure 1.2: Piconets with a single slave operation (a), a multi-slave operation (b) and a scatternet operation (c).

2 PHYSICAL CHANNEL

2.1 FREQUENCY BAND AND RF CHANNELS

Bluetooth operates in the 2.4 GHz ISM band. Although globally available, the exact location and the width of the band may differ by country. In the US and Europe, a band of 83.5 MHz width is available; in this band, 79 RF channels spaced 1 MHz apart are defined. In Japan, Spain, and France, a smaller band is available; in this band, 23 RF channels spaced 1 MHz apart are defined.

Country	Frequency Range	RF Channels	
Europe* & USA	2400 - 2483.5 MHz	f = 2402 + k MHz	k= 0,...,78
Japan	2471 - 2497 MHz	f = 2473 + k MHz	k= 0,...,22
Spain	2445 - 2475 MHz	f = 2449 + k MHz	k= 0,...,22
France	2446.5 - 2483.5 MHz	f = 2454 + k MHz	k= 0,...,22

Table 2.1: Available RF channels

*. except Spain and France

2.2 CHANNEL DEFINITION

The channel is represented by a pseudo-random hopping sequence hopping through the 79 or 23 RF channels. The hopping sequence is unique for the piconet and is determined by the Bluetooth device address of the master; the phase in the hopping sequence is determined by the Bluetooth clock of the master. The channel is divided into time slots where each slot corresponds to an RF hop frequency. Consecutive hops correspond to different RF hop frequencies. The nominal hop rate is 1600 hops/s. All Bluetooth units participating in the piconet are time- and hop-synchronized to the channel.

2.3 TIME SLOTS

The channel is divided into time slots, each 625 μs in length. The time slots are numbered according to the Bluetooth clock of the piconet master. The slot numbering ranges from 0 to 2^{27}-1 and is cyclic with a cycle length of 2^{27}.

In the time slots, master and slave can transmit packets.

A TDD scheme is used where master and slave alternatively transmit, see Figure 2.1 on page 44. The master shall start its transmission in even-numbered time slots only, and the slave shall start its transmission in odd-numbered time slots only. The packet start shall be aligned with the slot start. Packets transmitted by the master or the slave may extend over up to five time slots.

The RF hop frequency shall remain fixed for the duration of the packet. For a single packet, the RF hop frequency to be used is derived from the current Bluetooth clock value. For a multi-slot packet, the RF hop frequency to be used for the entire packet is derived from the Bluetooth clock value in the first slot of the packet. The RF hop frequency in the first slot after a multi-slot packet shall use the frequency as determined by the current Bluetooth clock value. Figure 2.2 on page 44 illustrates the hop definition on single- and multi-slot packets. If a packet occupies more than one time slot, the hop frequency applied shall be the hop frequency as applied in the time slot where the packet transmission was started.

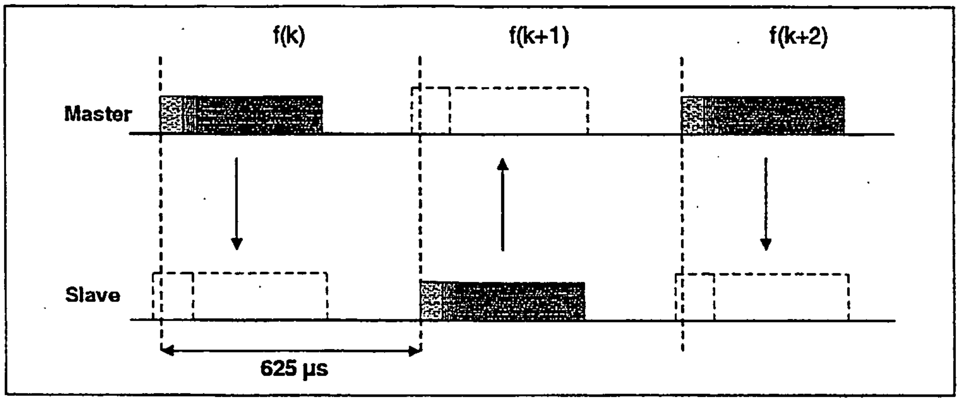

Figure 2.1: TDD and timing

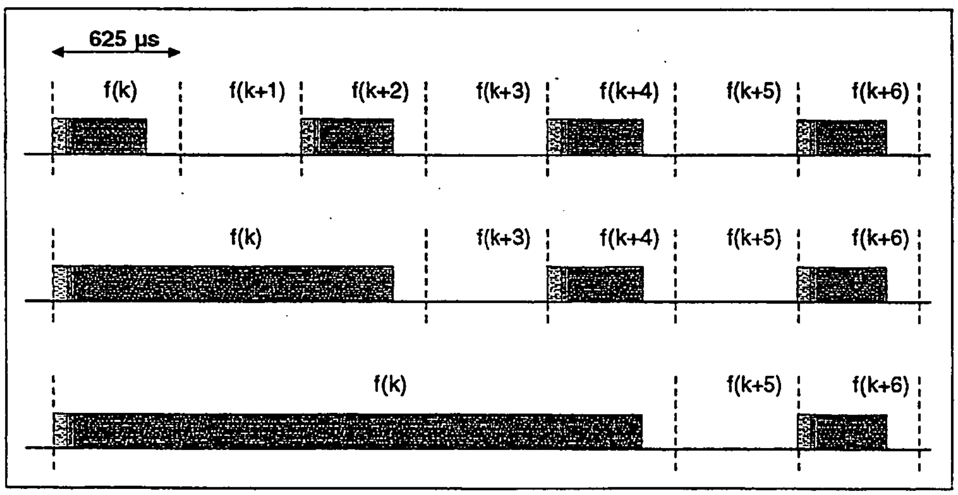

Figure 2.2: Multi-slot packets

2.4 MODULATION AND BIT RATE

The data transmitted has a symbol rate of 1 Ms/s. A Gaussian-shaped, binary FSK modulation is applied with a *BT* product of 0.5. A binary one is represented by a positive frequency deviation, a binary zero by a negative frequency deviation. The maximum frequency deviation shall be between 140 kHz and 175 kHz.

3 PHYSICAL LINKS

3.1 GENERAL

Between master and slave(s), different types of links can be established. Two link types have been defined:

- Synchronous Connection-Oriented (SCO) link
- Asynchronous Connection-Less (ACL) link

The SCO link is a point-to-point link between a master and a single slave in the piconet. The master maintains the SCO link by using reserved slots at regular intervals. The ACL link is a point-to-multipoint link between the master and all the slaves participating on the piconet. In the slots not reserved for the SCO link(s), the master can establish an ACL link on a per-slot basis to any slave, including the slave(s) already engaged in an SCO link.

3.2 SCO LINK

The SCO link is a symmetric, point-to-point link between the master and a specific slave. The SCO link reserves slots and can therefore be considered as a circuit-switched connection between the master and the slave. The SCO link typically supports time-bounded information like voice. The master can support up to three SCO links to the same slave or to different slaves. A slave can support up to three SCO links from the same master, or two SCO links if the links originate from different masters. SCO packets are never retransmitted.

The master will send SCO packets at regular intervals, the so-called SCO interval T_{SCO} (counted in slots) to the slave in the reserved master-to-slave slots. The SCO slave is always allowed to respond with an SCO packet in the following slave-to-master slot unless a different slave was addressed in the previous master-to-slave slot. If the SCO slave fails to decode the slave address in the packet header, it is still allowed to return an SCO packet in the reserved SCO slot.

The SCO link is established by the master sending an SCO setup message via the LM protocol. This message will contain timing parameters such as the SCO interval T_{SCO} and the offset D_{SCO} to specify the reserved slots.

In order to prevent clock wrap-around problems, an initialization flag in the LMP setup message indicates whether initialization procedure 1 or 2 is being used. The slave shall apply the initialization method as indicated by the initialization flag. The master uses initialization 1 when the MSB of the current master clock (CLK_{27}) is 0; it uses initialization 2 when the MSB of the current master clock (CLK_{27}) is 1. The master-to-slave SCO slots reserved by the master and the slave shall be initialized on the slots for which the clock satisfies the following equation:

$CLK_{27-1} \bmod T_{SCO} = D_{SCO}$ for initialization 1

$(\overline{CLK}_{27}, CLK_{26-1}) \bmod T_{SCO} = D_{SCO}$ for initialization 2

The slave-to-master SCO slots shall directly follow the reserved master-to-slave SCO slots. After initialization, the clock value CLK(k+1) for the next master-to-slave SCO slot is found by adding the fixed interval T_{SCO} to the clock value of the current master-to-slave SCO slot:

$CLK(k+1) = CLK(k) + T_{SCO}$

3.3 ACL LINK

In the slots not reserved for SCO links, the master can exchange packets with any slave on a per-slot basis. The ACL link provides a packet-switched connection between the master and all active slaves participating in the piconet. Both asynchronous and isochronous services are supported. Between a master and a slave only a single ACL link can exist. For most ACL packets, packet retransmission is applied to assure data integrity.

A slave is permitted to return an ACL packet in the slave-to-master slot if and only if it has been addressed in the preceding master-to-slave slot. If the slave fails to decode the slave address in the packet header, it is not allowed to transmit.

ACL packets not addressed to a specific slave are considered as broadcast packets and are read by every slave. If there is no data to be sent on the ACL link and no polling is required, no transmission shall take place.

4 PACKETS

4.1 GENERAL FORMAT

The bit ordering when defining packets and messages in the *Baseband Specification*, follows the *Little Endian format*, i.e., the following rules apply:

- The *least significant bit* (LSB) corresponds to b_0;
- The LSB is the first bit sent over the air;
- In illustrations, the LSB is shown on the left side;

The baseband controller interprets the first bit arriving from a higher software layer as b_0; i.e. this is the first bit to be sent over the air. Furthermore, data fields generated internally at baseband level, such as the packet header fields and payload header length, are transmitted with the LSB first. For instance, a 3-bit parameter X=3 is sent as $b_0 b_1 b_2 = 110$ over the air where 1 is sent first and 0 is sent last.

The data on the piconet channel is conveyed in packets. The general packet format is shown in Figure 4.1 on page 47. Each packet consists of 3 entities: the access code, the header, and the payload. In the figure, the number of bits per entity is indicated.

LSB 72	54	0 - 2745 MSB
ACCESS CODE	HEADER	PAYLOAD

Figure 4.1: Standard packet format.

The access code and header are of fixed size: 72 bits and 54 bits respectively. The payload can range from zero to a maximum of 2745 bits. Different packet types have been defined. Packets may consist of the (shortened) access code only (see ID packet on page 55), of the access code – header, or of the access code – header – payload.

4.2 ACCESS CODE

Each packet starts with an access code. If a packet header follows, the access code is 72 bits long, otherwise the access code is 68 bits long. This access code is used for synchronization, DC offset compensation and identification. The access code identifies all packets exchanged on the channel of the piconet: all packets sent in the same piconet are preceded by the same channel access code. In the receiver of the Bluetooth unit, a sliding correlator correlates against the access code and triggers when a threshold is exceeded. This trigger signal is used to determine the receive timing.

The access code is also used in paging and inquiry procedures. In this case, the access code itself is used as a signalling message and neither a header nor a payload is present.

The access code consists of a preamble, a sync word, and possibly a trailer, see Figure 4.2 on page 48. For details see Section 4.2.1 on page 48.

LSB 4	64	4 MSB
PREAMBLE	SYNC WORD	TRAILER

Figure 4.2: Access code format

4.2.1 Access code types

There are three different types of access codes defined:

- Channel Access Code (CAC)
- Device Access Code (DAC)
- Inquiry Access Code (IAC)

The respective access code types are used for a Bluetooth unit in different operating modes. The channel access code identifies a piconet. This code is included in all packets exchanged on the piconet channel. The device access code is used for special signalling procedures, e.g., paging and response to paging. For the inquiry access code there are two variations. A general inquiry access code (GIAC) is common to all devices. The GIAC can be used to discover which other Bluetooth units are in range. The dedicated inquiry access code (DIAC) is common for a dedicated group of Bluetooth units that share a common characteristic. The DIAC can be used to discover only these dedicated Bluetooth units in range.

The CAC consists of a **preamble, sync word,** and **trailer** and its total length is 72 bits. When used as self-contained messages without a header, the DAC and IAC do not include the trailer bits and are of length 68 bits.

The different access code types use different Lower Address Parts (LAPs) to construct the sync word. The LAP field of the BD address is explained in Section 13.1 on page 143. A summary of the different access code types can be found in Table 4.1 on page 49.

Code type	LAP	Code length	Comments
CAC	Master	72	See also Section 13.2 on page 143
DAC	Paged unit	68/72	
GIAC	Reserved	68/72*	
DIAC	Dedicated	68/72	

Table 4.1: Summary of access code types.

*. length 72 is only used in combination with FHS packets

4.2.2 Preamble

The preamble is a fixed zero-one pattern of 4 symbols used to facilitate DC compensation. The sequence is either 1010 or 0101, depending whether the LSB of the following sync word is 1 or 0, respectively. The preamble is shown in Figure 4.3 on page 49.

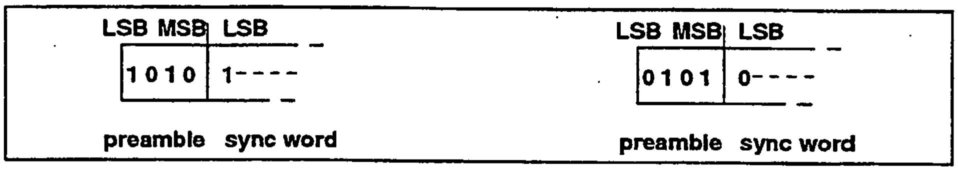

Figure 4.3: Preamble

4.2.3 Sync Word

The sync word is a 64-bit code word derived from a 24 bit address (LAP); for the CAC the master's LAP is used; for the GIAC and the DIAC, reserved, dedicated LAPs are used; for the DAC, the slave unit LAP is used. The construction guarantees large Hamming distance between sync words based on different LAPs. In addition, the good autocorrelation properties of the sync word improve on the timing synchronization process. The derivation of the sync word is described in Section 13.2 on page 143

4.2.4 Trailer

The trailer is appended to the sync word as soon as the packet header follows the access code. This is typically the case with the CAC, but the trailer is also used in the DAC and IAC when these codes are used in FHS packets exchanged during page response and inquiry response procedures.

The trailer is a fixed zero-one pattern of four symbols. The trailer together with the three MSBs of the syncword form a 7-bit pattern of alternating ones and zeroes which may be used for extended DC compensation. The trailer sequence is either 1010 or 0101 depending on whether the MSB of the sync word is 0 or 1, respectively. The choice of trailer is illustrated in Figure 4.4 on page 50.

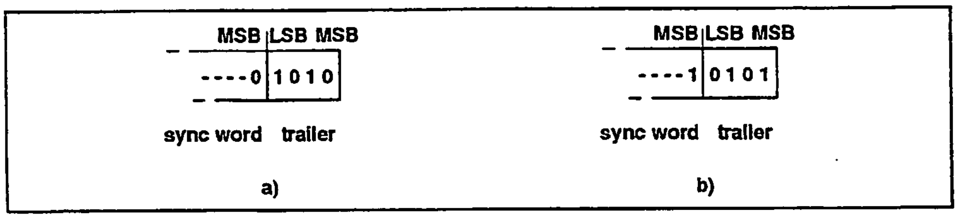

Figure 4.4: Trailer in CAC when MSB of sync word is 0 (a), and when MSB of sync word is 1 (b).

4.3 PACKET HEADER

The header contains link control (LC) information and consists of 6 fields:

- AM_ADDR: 3- bit active member address
- TYPE: 4-bit type code
- FLOW: 1-bit flow control
- ARQN: 1-bit acknowledge indication
- SEQN: 1-bit sequence number
- HEC: 8-bit header error check

The total header, including the HEC, consists of 18 bits, see Figure 4.5 on page 51, and is encoded with a rate 1/3 FEC (not shown but described in Section 5.1 on page 67) resulting in a 54-bit header. Note that the AM_ADDR and TYPE fields are sent with their LSB first. The function of the different fields will be explained next.

LSB 3	4	1	1	1	8 MSB
AM_ADDR	TYPE	FLOW	ARQN	SEQN	HEC

Figure 4.5: Header format.

4.3.1 AM_ADDR

The AM_ADDR represents a member address and is used to distinguish between the active members participating on the piconet. In a piconet, one or more slaves are connected to a single master. To identify each slave separately, each slave is assigned a temporary 3-bit address to be used when it is active. Packets exchanged between the master and the slave all carry the AM_ADDR of this slave; that is, the AM_ADDR of the slave is used in both master-to-slave packets and in the slave-to-master packets. The all-zero address is reserved for broadcasting packets from the master to the slaves. An exception is the FHS packet which may use the all-zero member address but is *not* a broadcast message (Section 4.4.1.4 on page 56). Slaves that are disconnected or parked give up their AM_ADDR. A new AM_ADDR has to be assigned when they re-enter the piconet.

4.3.2 TYPE

Sixteen different types of packets can be distinguished. The 4-bit TYPE code specifies which packet type is used. Important to note is that the interpretation of the TYPE code depends on the physical link type associated with the packet. First, it shall be determined whether the packet is sent on an SCO link or an ACL link. Then it can be determined which type of SCO packet or ACL packet has been received. The TYPE code also reveals how many slots the current packet will occupy. This allows the non-addressed receivers to refrain

from listening to the channel for the duration of the remaining slots. In Section 4.4 on page 54, each packet type will be described in more detail.

4.3.3 FLOW

This bit is used for flow control of packets over the ACL link. When the RX buffer for the ACL link in the recipient is full and is not emptied, a STOP indication (FLOW=0) is returned to stop the transmission of data temporarily. Note, that the STOP signal only concerns ACL packets. Packets including only link control information (ID, POLL and NULL packets) or SCO packets can still be received. When the RX buffer is empty, a GO indication (FLOW=1) is returned. When no packet is received, or the received header is in error, a GO is assumed implicitly.

4.3.4 ARQN

The 1-bit acknowledgment indication ARQN is used to inform the source of a successful transfer of payload data with CRC, and can be positive acknowledge ACK or negative acknowledge NAK. If the reception was successful, an ACK (ARQN=1) is returned, otherwise a NAK (ARQN=0) is returned. When no return message regarding acknowledge is received, a NAK is assumed implicitly. NAK is also the default return information.

The ARQN is piggy-backed in the header of the return packet. The success of the reception is checked by means of a cyclic redundancy check (CRC) code. An unnumbered ARQ scheme which means that the ARQN relates to the latest received packet from the same source, is used. See Section 5.3 on page 68 for initialization and usage of this bit.

4.3.5 SEQN

The SEQN bit provides a sequential numbering scheme to order the data packet stream. For each new transmitted packet that contains data with CRC, the SEQN bit is inverted. This is required to filter out retransmissions at the destination; if a retransmission occurs due to a failing ACK, the destination receives the same packet twice. By comparing the SEQN of consecutive packets, correctly received retransmissions can be discarded. The SEQN has to be added due to a lack of packet numbering in the unnumbered ARQ scheme. See section 5.3.2 on page 70 for initialization and usage of the SEQN bit. For broadcast packets, a modified sequencing method is used, see Section 5.3.5 on page 72.

4.3.6 HEC

Each header has a header-error-check to check the header integrity. The HEC consists of an 8-bit word generated by the polynomial 647 (octal representation). Before generating the HEC, the HEC generator is initialized with an 8-bit value. For FHS packets sent in **master page response** state, the slave upper

address part (UAP) is used. For FHS packets sent in **inquiry response**, the default check initialization (DCI, see Section 5.4) is used. In all other cases, the UAP of the master device is used. For the definition of Bluetooth device addresses, see Section 13.1 on page 143.

After the initialization, a HEC is calculated for the 10 header bits. Before checking the HEC, the receiver must initialize the HEC check circuitry with the proper 8-bit UAP (or DCI). If the HEC does not check, the entire packet is disregarded. More information can be found in Section 5.4 on page 73.